EFFECTS OF PEER-TUTOR COMPETENCES ON LEARNER COGNITIVE LOAD AND LEARNING PERFORMANCE DURING KNOWLEDGE SHARING

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ABSTRACT

KEYWORDS

peer-tutor competence, content knowledge, tutoring skills, knowledge sharing, cognitive load, tutor selection.

1. INTRODUCTION

A Learning Network (LN) is a particular kind of online social network that is dedicated to learning (Sloep 2009). In LNs, learners are themselves responsible for sharing knowledge with their peer learners. In particular, when working on complex tasks it is very likely that learners need to share knowledge with others to acquire more cognitive resources (Kirschner et al. 2009). When organizing knowledge sharing themselves, learners first have to find out relevant knowledge sharers and then maintain the social interaction with others to reach a shared understanding and knowledge building. Without support, organizing these two activities on complex tasks easily overloads learners' limited cognitive capacities (Hsiao et al. 2011). To help finding relevant knowledge sharers, our colleagues have developed two tutor selection systems that automatically assign peer learners to act as peer tutors to help answer each others' content-related questions based on certain competence criteria (Van Rosmalen 2008; De Bakker 2010). *Content competence* refers knowledge related to the question that either is acquired during participation in the LN (Van Rosmalen 2008; De Bakker 2010) or the prior knowledge that learners bring into a LN (De Bakker 2010). *Tutoring competence* is either defined objectively as "the ability of a peer learner to act as a tutor" by using actual performance data of how a peer tutor behaved in previous questions (Van Rosmalen 2008) or subjectively as learners' perceived competency of which question type (i.e., theoretical or organizational questions) they are competent to help (De Bakker 2010). However, due to the scope of their research, the effects of tutors with particular tutor competence on tutee learning have *not* been investigated.

To avoid confusion, we use the term *peer-tutor competence* to encompass Van Rosmalen and De Bakker's content and tutor competence but we substitute these two terms with *content knowledge* and *tutoring skills*. Please note that these tutor selection systems aimed to involve peers to support each other's content-related questions and they have shown that peer tutors who are non-professional teachers could provide satisfactory answers without involving teachers' help (Van Rosmalen et al. 2008; Van Rosmalen et al. 2008; De Bakker 2010). However, due to the heterogeneous group composition of LNs it is not always possible to find tutors with content knowledge related to tutees' questions. In addition, the questions or problems that participants of LNs have are often rather complex: they are authentic problems originating from real-life contexts, such as the working place.

When working on complex tasks, learners have to allocate many of their cognitive resources to process numerous information elements and element interactivity and this imposes a high cognitive load (Sweller 2006). Cognitive load (or mental workload) refers to the learner's limited cognitive capacity actually allocated on performing a particular task and it has been recognized as an important factor that influences learner performance (Paas and Van Merriënboer 1994; Sweller et al. 1998; Xie and Salvendy 2000). We surmise that tutors who provide content-related knowledge *only* cannot alleviate their tutees' cognitive load. The reason is that this load is imposed by complex tasks that require higher cognitive skills to process a number of information elements and element interactivity simultaneously. Our doubt aligns with the doubts voiced by several researchers of tutoring. Their studies show inconclusive effects of tutor content knowledge on tutee learning (De Grave et al. 1990; Silver and Wilkerson 1991).

Furthermore, maintaining the social interaction to reach a shared understanding or build knowledge on complex tasks requires certain pedagogical and process-facilitation skills (Schmidt et al. 1995; King et al. 1998; Roscoe and Chi 2007; Roscoe and Chi 2008). These skills go beyond the knowledge transfer or information exchange that content tutors often offer. If it is not possible to always find tutors with content knowledge precisely related to tutees' questions, nor do tutors with content knowledge guarantee effective tutee learning. It is therefore necessary to consider tutors with tutoring skills. However, while most tutoring studies have examined effects of tutors' content knowledge on diverse dependent variables of tutees, there have *not* been many studies that measured effects of tutors' tutoring skills on tutees' learning (Nückles et al. 2006). Studies of *reciprocal* peer tutoring have compared the effects of supporting learners *with* and *without* tutoring skills on learner performance (King 1994; King et al. 1998; Nath and Ross 2001). Their support of tutoring skills was to make sure that learners would demonstrate tutoring skills to elicit certain social interactions and trigger cognitive processes that contribute to learning. Some studies have shown that the learners with tutoring skills outperformed the control groups on knowledge or comprehension tests (King 1994; King et al. 1998). However, in LNs knowledge sharing involving peer support is more akin to *asymmetric* rather than reciprocal peer tutoring. From these studies we can therefore only speculatively claim that tutoring skills are likely to promote tutee learning. .

Considering human limited cognitive capacities, when designing a peer support system in LNs we should first decrease cognitive load imposed in finding tutors with relevant content knowledge. Our previous work of using automated tutor selection systems might have potential to achieve this. But as just argued, it most likely requires certain tutoring skills actually to alleviate tutees' cognitive load imposed by complex tasks, such as the communication and coordination processes involved in knowledge sharing. Thus, we need to redesign our previous tutor selection system to figure out what makes an effective tutor and to design support for the social interaction process. To achieve this, we first of all need to investigate the effects of peer tutor competences, i.e. content knowledge vs. tutoring skills, on tutee learning. In this pilot study we investigate whether it is possible to determine an effect of the two types of peer-tutor competence when tutors do not receive prior training but instead receive a tutoring guide that to follow.

2. METHOD

2.1 Participants and settings

Two computer science classes jointly consisting of 28 students from a pre-university secondary school in the Netherlands took part in this study. They were in their final fifth and sixth grade, just before entering university, aged 16-18 years. The school received parents' permission for these students' participation. All students received a reward of an I-tune voucher. This pilot was conducted on two websites: the course site contains the learning material of *Sex and Evolution* as well as the task site contains task instructions, chat and wiki tools.

2.3 Design and procedures

We assigned students in half of classes to act as tutors and the other half as tutees. The tutor role was split: a tutor was either a tutoring skills (TS) or a content knowledge (CK) tutor. In total there were seven TS and seven CK pairs. The intervention of this study was to provide tutors with a tutoring guide including additional course materials (for CK tutors) or instructions of tutoring skills (for TS tutors) to assure that tutors had either CK or TS competence. This pilot study consisted of two sessions in 2.5 hours. During the first session, students studied the learning material on the course site and then they took the pre-test and filled in the Tutoring Skills Questionnaire. There was a 15-minute break between these two sessions. The second session was started with a brief introduction of peer tutoring, task requirements and use of chat and wiki tools. Then students had 50 minutes to work in pairs to complete the essay task. While performing the task, students no longer could consult the course material. When working on the task, students had to use a chat to communicate with each other and they were not allowed to talk face-to-face. Tutees had to write the essay in a wiki and to "publish" the wiki page frequently to allow the tutors to read up on the tutee's progress. Tutors could only read the wiki page, but they could not edit it. To view the updated wiki page, tutors had to "refresh" the wiki page frequently. Tutors used a respective tutoring guide to help tutees work on essay answers through the chat. After the task, students had 20 minutes to indicate experienced cognitive load on the NASA-Task Load Index, to take the post-test and to fill in an evaluation survey.

2.4 Materials

2.4.1 Pre- and post-test

Before students worked on the assigned task, they completed a short quiz consisting of ten multiple-choice questions to test their knowledge about Sex and Evolution. After they completed the task, we used a post-test of 15 multiple-choice questions to measure students' learning performance. This post-test consisted of the same ten items in the pre-test and another five task-related items that measured understanding of the topics included in the task.

2.4.2 Tutoring Skills Questionnaire

The Tutoring Skills Questionnaire consisted of 15 items measuring students' pedagogical and process-facilitation skills, such as "I am good at explaining." and "I use divers question starters, such as what, how, why, etc.". Students rated themselves for each item on a 5-point Likert-type scale, ranging from 1 (strongly disagree) to 5 (strongly agree). The overall score for tutoring skills was obtained by summing up the scores of all 15 items, resulting in a minimum total raw score of 5 to maximum 75.

2.4.3 Task

Only those students who acted as tutees had to write an essay up to half A4 as measure of their grasp of the course materials *Sex and Evolution*. The essay question is: "Compare and contrast gender differences in partner selection and different forms of relationship". We regarded this essay as a complex task because students had to compare and contrast multiple interactive information elements simultaneously (Mayer 2002) to answer this question.

2.4.4 Cognitive load measure

We used the NASA-Task Load Index (NASA-TLX) to measure students' cognitive load (mental workload). The NASA-TLX consists of six dimensions that ask learners to indicate experienced workload on several dimensions when performing a task: mental, physical, temporal demands, frustration, effort and performance (Hart and Stavelend 1988; Hart 2006). All scales range from "low" to "high" and are divided into 20 sections except for the performance scale that ranges from "good" to "poor". Students have to tick one of the 20 sections that best represents their perceived load for each of the dimensions. The response score ranges from 1 to 20, where a high score indicates a higher level of cognitive load. A description including examples is provided for every dimension. For example, the description for mental demand states "How much mental demand and perceptual activity was required? (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?"

2.4.5 Evaluation survey

We made a 12-item survey to ask tutors and tutees to evaluate the tutoring process, their seriousness and motivation when working on the task. Students respond on a Likert-like five-point scale (from 1, "strongly disagree” to 5, “strongly agree”). Sample items for tutee survey include “The tutoring was useful for task completion.” and “My tutor’s explanations helped me do the task.” Sample items for tutor survey include “My tutoring was useful for my tutee to complete his/her task.” and “I used the supplement texts/prompt of tutoring skills during tutoring.” We scored the results in the same way as Tutoring Skills Questionnaire.

2.4.6 Tutoring guides

All tutors received a tutoring guide to use while assisting their tutees to work on the essay task. The guides consisted of several sections: a description of the essay task, instructions of using the chat tool for communication and the wiki for constructing the essay, tutor role tasks. Furthermore, the guide includes a specific section that supports tutors to have competence in either content knowledge or tutoring skills: CK tutors received additional course materials; TS tutors received instructions consisted of general rules for pedagogical and process-facilitation skills as well as specific step-by-step directions that guide tutors to perform pedagogical and process-facilitation skills (King 2007).

2.5 Data analysis

Since we piloted this study on a very small sample size (i.e., only seven pairs for TS or CK), we did not intend to do statistical tests to compare groups; instead, we described the results to examine how CK tutors and TS tutors influenced each tutee dependent variable. Therefore, only descriptive statistics are given in Results. We processed and reported four dependent variables as follows: 1) test performance was obtained from scores of the post-test and the five task-related questions, 2) essay performance was obtained from the total scores of four criteria because we assessed essay answers based on focus, organization, support, and accuracy, 3) because the essay question required students to generate answers on multiple topics, we further identified and counted number of topics that were answered completely or partially in essays, 4) cognitive load was obtained from NASA-Task Load Index. Moreover, during the experiment, we observed that some tutors might not apply the support of competences when chatting with their tutees. To get a better indication of the effect of the tutoring competence we looked at the various measures for tutees for which the tutors definitely adhered to the tutoring competence. As for reliability coefficients, we calculated Cronbach’s Alpha (α) to represent the internal consistency of scores on the pre-test, Tutoring Skills Questionnaire, essay scores on four criteria and scores of six subscales on NASA-TLX.

3. RESULTS

3.1 Tutee learning performance

Both groups of tutees estimated their tutoring skills to be quite high, 63 out of possible 75. There was no difference between tutees assigned to TS (M = 63.71, SD = 3.95) or CK (M = 63.57, SD = 5.41) pairs. The low pre-test scores showed that tutees of both groups did not have sufficient prior knowledge though TS tutees scored slightly higher than CK tutees. Please note that the internal consistency of this pre-test is rather *low* (α = 0.4).

Table 1 shows the results of performance measures. The test-retest reliability is .60 (p = .03), which shows a statistically significant correlation of the same ten items between pre- and post-test. Tutees’ low post-test scores indicated that working on the essay task did not help students learn much related to the course materials. CK tutees performed better on five task-related items than TS tutees: this means that additional course materials might help tutees understand the topics included in the essay task better than instructions of tutoring skills.

Table 1. Performance on the essay, post-test, task-related items and learning gains

	total score	TS-tutees		CK-tutees	
		M	*SD*	*M*	*SD*
pre-test	10	5.00	2.00	4.00	.89
post-test	10	5.57	1.90	4 .57	1.27

5 task-related items	10	3.71	2.14	4.29	2.14
essay	10	6.90	1.27	6.72	1.46

The internal consistency of essay scores on four criteria is good (α = .81). Both groups of tutees performed equally well on essay answers though TS tutees performed slightly better than CK tutees. From Table 2 we see that TS tutees answered more topics completely than CK tutees whereas CK-tutees answered more topics partially than TS-tutees.

Table 2. Frequencies of topics answered completely and partially

	TS-tutees		CK-tutees	
	M	*SD*	*M*	*SD*
completely answered	2.00	.82	1.86	.69
partially answered	2.43	.98	2.71	1 .70

3.2 Tutee cognitive load

The NASA-TLX was found to be acceptably reliable (α = .74) and when the *temporal demand* is not considered the internal consistency can be increased to .79. TS tutees' total cognitive load is lower than CK tutees' and lower on all six dimensions. In particular, TS tutees experienced much lower cognitive load on *physical demand* and *frustration* than CK tutees. From the modes, we can see that TS tutees experienced lower cognitive load on five sub-scales except *performance*. This might explain why TS tutees had fewer learning gains and performed worse on the five task-related items than CK tutees (see Table 1). Of course, these results must be treated with caution in view of the small sample size.

Table 3. Tutee cognitive load on six dimensions of NASA-TLX

		Mental demand	Physical demand	Temporal demand	Performance	Effort	Frustration	Total
TS	Mean	11.29	4.71	9.43	8.00	9.43	5.57	48.43
	Median	12.00	3.00	10.00	6.00	9.00	2.00	41.00
	Mode	7.00	3.00	1.00[a]	6.00	6.00[a]	1.00[a]	35.00[a]
	SD	4.27	3.82	6.05	3.70	4.08	5.68	14.60
		Mental demand	Physical demand	Temporal demand	Performance	Effort	Frustration	Total
CK	Mean	12.71	9.00	10.07	7.86	11.50	10.93	62.07
	Median	14.00	11.00	10.50	8.00	13.00	10.50	68.00
	Mode	14.00	12.00	4.00[a]	1.00[a]	14.00	10.00[a]	21.50[a]
	SD	5.59	4.32	4.66	4.67	3.93	2.78	20.01

[a] multiple modes

3.3 Tutee cognitive load and learning performance when their tutors applied the tutoring guide

Chats were analyzed for evidence of adherence to the assigned tutoring competence. Only two of the TS tutors applied the *specific* step-by-step instructions and five of the CK tutors referred to the additional course material. Table 5 shows that TS tutees performed better on all performance measures and they experienced lower cognitive load than CK tutees.

The TS tutees involved performed better (scores of 7 and 8.8 respectively) on the essay than other TS tutees (M = 6.50, SD = 1.13) and CK tutees (M = 6.72, SD = 1.46), but experienced higher total cognitive load (M = 51.00, SD = 14.14) than the other TS tutees whose tutors did not apply the specific step-by-step instructions (M = 47.40, SD = 16.29). Given their better essay scores, a likely explanation could be that TS tutees allocated cognitive resources to learning.

Of the seven CK tutors, five referred to the additional course materials in the chats. Their paired CK tutees experienced relatively higher cognitive load (*M* = 68.20, *SD* = 10.85) than the remaining CK tutees (*M* = 46.75, *SD* = 35.71) or the TS tutees (*M* = 48.43, *SD* = 14.60). In contrast, these five CK tutees (*M* = 6.71, *SD* = 1.78) did *not* perform better than the other two CK tutees (*M* = 6.75, *SD* =.11) or the TS tutees (*M* = 6.90, *SD* = 1.27).

Table 5. Performance measures and cognitive load of TS tutees and CK tutees supported by tutors who actually applied intervention during chats

	TS-tutees (*n* = 2)		CK-tutees (*n* = 5)	
	M	*SD*	*M*	*SD*
pre-test	5.00	2.83	3.75	.96
post-test	6.50	3.54	4.40	1.52
5 task-related items	4.00	0	3.60	1.67
essay	7.92	1.29	6.71	1.78
total cognitive load	51.00	14.14	68.20	10.85

4. CONCLUSION AND DISCUSSION

Although TS tutees had higher scores on the essay task and post-test, CK tutees seemed to have higher scores on the five task-related items than TS tutees. From how multiple topics were answered in the essays, we surmise that the different tutor competences influenced how tutees worked on the task. The diverse examples included in the additional course materials helped CK tutees answer more topics partially while the instructions that TS-tutors used helped TS tutees answer topics more completely. When looking into the data of tutees supported by tutors who *indeed* applied the intervention of additional course materials and tutoring skills, the results in Table 5 turned out to be different from the group data in Table 1: TS tutees performed better than CK tutees on both test and task measures.

During knowledge sharing, CK tutees in general experienced more cognitive load than TS tutees. In particular, the much lower score on *frustration* corresponds to findings of our previous study (Hsiao et al. in press). We observed that some CK pairs completed the task much earlier than the expected time of 50 minutes. Although using additional course materials helped CK tutees complete the task earlier, CK-tutees still indicated a high cognitive load. Furthermore, for pairs whose tutors indeed applied the intervention, TS tutees who spent more time on processing the task experienced lower cognitive load than CK tutees who could complete the task earlier. Altogether, these might explain why *temporal demand* is less internally correlated with other scales of NASA-TLX.

The findings of this pilot are hopeful in the sense that discerning CK and TS tutoring competences seems to make sense. In order to corroborate our first findings, we need to improve four aspects for the full study, they relate to: i) how to measure learning performance, ii) how best to design tasks, iii) how to ensure tutors adhere to the assigned tutor competence and iv) how to analyze tutors' use of the intervention. In this study we tried out different performance measures in order to find out which could clearly answer the research question in the full study. The pre- and post-test that measured students' understanding of the entire course could not appropriately gauge the effects of the intervention on the essay task since this essay only covered several topics of the course. Thus, to better measure learning performance, we should either expand the number of task-related items to a longer test or use the essay answers that directly reflect how students learn from working on the task.

Tasks with different complexities require different amount of cognitive resources to deal with the task load. Complexities of essay questions not only depend on the interactivity of information elements but also on the level of cognitive skills required. The essay question of this study is still a relatively *simple* task: comparing and contrasting facts require a lower level of cognitive skills, namely understanding. From satisfactory essay scores, we surmise that tutees might be able to answer the essay by merely retrieving learned factual knowledge from their own or their tutors' memory instead of performing higher cognitive skills to process the task load. This corresponds to our model that when working on simple tasks learners do not need to resort to knowledge sharing or that knowledge sharing does not contribute to better learning effects (Hsiao et al. 2011).

Considering the online characteristics of LNs, we supported tutors with certain competences by giving them ready-to-use tutoring guides instead of giving them a prior training, as is commonly done in online collaborative learning studies or peer tutoring in face-to-face classrooms. The results showed that five of seven CK tutors and two of seven TS tutors and applied the respective intervention. Our findings confirm the findings of peer tutoring studies: without training, peer tutors seldom demonstrate certain skills to fulfill their role tasks (Nath and Ross 2001; Smet et al. 2010). Our observations during the experiment might explain why TS tutors did not use tutoring skills: 1) tutors might not have sufficient time to read all of the textual instructions, 2) tutors might not realize the relevance of using the general instructions with answering the essay question, and 3) students might have developed certain internal scripts of dealing with such essay questions comparing facts and thus they did not need to use our intervention.

To ascertain whether tutors applied the intervention, we examined the chats when tutors and tutees communicated to process the essay. While it is straightforward to check whether CK tutors used additional course materials, checking whether TS tutors applied instructions of tutoring skills requires qualitative analysis of how language functions in social interaction. Please note that the current intervention of tutoring skills include both general and specific instructions but in fact we only checked the use of *specific* instructions in Results (see Section 3.3). To understand how general instructions are internalized and used, we need to conduct a discourse analysis to deeply examine the moves and speech acts that TS tutors exhibited during chats.

To conclude, for the full study we need to *oblige* tutors to apply the support of competences as we expected, in particular for tutors to apply tutoring skills. In addition, we should implement the full study with a more complex task that requires higher-order cognitive skills such as analysis, evaluation and synthesis, to make sure that learners benefit from the kind of knowledge sharing with others that triggers extra cognitive processes.

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